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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 : H01J 5/16, G01D 5/34 G02B 6/02 A1

(11) International Publication Number: WO 88/ 02545

(43) International Publication Date: 7 April 1988 (07.04.88)

(21) International Application Number: PCT/US87/02404

(22) International Filing Date: 23 September 1987 (23.09.87)

(31) Priority Application Number: 915,115

(32) Priority Date: 3 October 1986 (03.10.86)

(33) Priority Country: US

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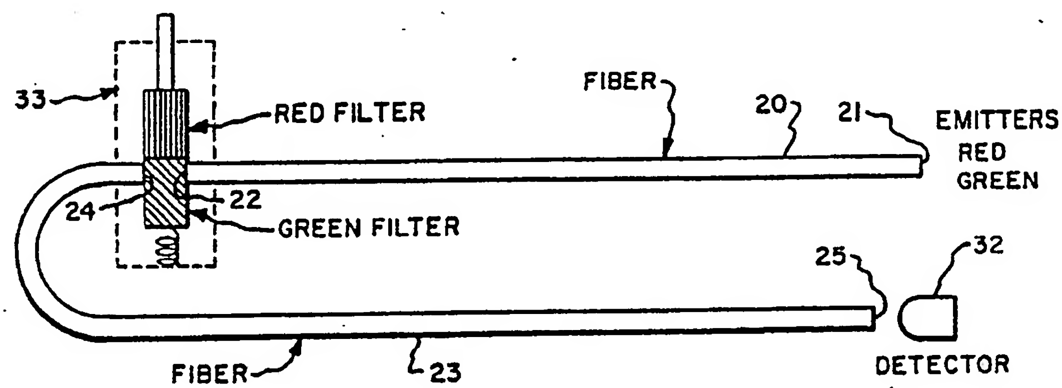
(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), SE (European patent).

Published
With international search report.
With amended claims.

(54) Title: FIBER OPTIC SENSOR APPARATUS



(57) Abstract

An optical apparatus for measuring physical quantities, comprising an optical transducer (33) for sensing position, outgoing and return optical fibers (20, 23), and an electronic sensor control module (43). Light is generated at the control module and transmitted by the outgoing optical fiber (20) to the optical transducer (33) which varies relative intensity of two colors in a dissimilar manner in response to location of a positionable device (34, 35) in the optical transducer. The modified intensity is transmitted back to the control module via the return optical fiber (23). The control module (43) measures the intensity of the two returning colors, and then outputs an electrical signal proportional to the intensity ratio for analog applications, or alternatively tests the intensity ratio against preselected constants and outputs discrete signals for digital applications. The control module can, in addition, incorporate self-testing of the optical components.

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DESCRIPTION

FIBER OPTIC SENSOR APPARATUS

TECHNICAL FIELD

The present invention relates to the technical field of fiber optics, and more particularly to fiber optic sensor apparatus.

BACKGROUND ART

Factory automation requires extremely reliable limit switches and position sensors that are immune to electromagnetic induction. Also, certain industries, such as in the petrochemical and energy fields, require intrinsically safe switch devices in hazardous locations. Further, there is a major effort to develop aircraft and ships with an optical fiber control system. As well, the automotive industry is increasing the use of fiber optics.

In the prior art, various measuring devices are known for measuring a physical parameter by measuring the intensity of light. In these devices, light from one or more light sources is transmitted via an outgoing optical fiber to an optical transducer which, in proportion to the sensed property, controls the amount of light transmitted back via a return optical fiber. Photodetection apparatus is used to convert the returned light intensity to suitable electrical signals. It is known that mechanical effects such as bending the fiber and remating connectors, as well as environmental effects such as temperature and pressure, can also affect the intensity of the light. Multiple light sources and detectors can be used to compensate for these undesirable effects.

As described previously in United States Patent 4,356,396, light of two wavelengths is generated and two detectors monitor the outgoing light and two detectors monitor the returning light. One of the wavelengths of light is reflected back by a mirror between the optical fiber and optical transducer and provides a reference intensity for the compensation calculation. The transducer acts only upon the second wavelength of light, thus it is not possible to make corrections for mechanical or environmental perturbations in the transducer itself.

Optical transducers acting on more than one wavelength of light

are also known. For instance, United States Patents 4,514,860, 4,417,140 and 4,378,496 require two light emitting diodes and associated electronic components in the transducer assembly. A transducer operating without any electric current or voltage is desired to reduce the hazard associated with electrical devices.

Further, multiple wavelengths of light have been used in transducer assemblies in the prior art to make multiple measurements. The technique, as described in United States Patent 4,523,092, does not compensate for environmental or mechanical perturbations in the transducer.

Another example of using two wavelengths is described in United States Patent 4,492,860, but only a single fiber is used and polarization is employed to control reflection of the outgoing light into detector apparatus.

DISCLOSURE OF THE INVENTION

Generically, the invention contemplates fiber optic sensor apparatus which provides a ratio of detected output light intensities of two different bands of light having spectral distributions centered at two different wavelengths, the magnitude of the ratio corresponding to the position of an optical transducer and being utilized by an electronic signal processor. The light intensities of the two bands of light may be detected, either by a broadband detector from wavelength discriminant light sources, or by wavelength discriminant detectors from a broadband light source. In other words, equivalent results can be produced by a multiple light source cooperating with a single detector, or by a single light source cooperating with multiple detectors.

It is an object of the present invention to provide fiber optic sensor apparatus for discrete or proportional sensing of a physical parameter, i.e., to provide digital operation such as for a switch, or to provide analog operation for position measurement or control.

It is another object of this invention to provide such fiber optic sensor apparatus which is self-calibrating so that light sensitivity adjustment is not required.

It is still another object of this invention to provide such fiber optic sensor apparatus which is self-monitoring to indicate malfunction when any of the optical components fail.

It is still another object of this invention to provide such fiber optic sensor apparatus which can be easily serviced in the field by visually

checking the functionality of the optical circuit without requiring special test equipment.

It is still another object of this invention to provide such fiber optic sensor apparatus which is intrinsically safe since no electrical current or voltage is supplied to or generated at the place of position sensing.

Other objects and advantages of the present invention will be apparent from the ensuing detailed illustration and description of preferred embodiments which carry out the invention by a broadband detector detecting the light intensities of two bands of light generated by wavelength discriminant light sources.

According to the present invention, a fiber optic sensor apparatus contains an outgoing optical fiber having input and output ends, and a return optical fiber having input and output ends. The apparatus also contains a first light source for generating a first light having a spectral distribution centered at a first wavelength, and a second light source for generating a second light having a spectral distribution centered at a second wavelength. The first wavelength is different from the second wavelength. Both light sources may be part of a dual color light generating unit. These dual light sources may be operated alternately and include a suitable optical element for directing their respective light beams into the input end of the outgoing optical fiber. As a result, the first and second light beams will be transmitted from the input end to the output end of the outgoing optical fiber.

The apparatus further contains an optical transducer operatively arranged between the output end of the outgoing optical fiber and the input end of the return optical fiber. This transducer includes a positionable device and an actuator for moving such device. The optical transducer modifies the intensity of the first and second lights, at the input end of the return optical fiber, in a dissimilar manner as a function of the change in position of the positionable device.

The optical transducer may be of the transmissive type in which its positionable device includes a first optical filter that preferentially transmits the first light, and a second optical filter that preferentially transmits the second light, such filters acting in cooperation such that the relative amount of the first light and the second light transmitted into the return optical fiber changes with the position of the actuator.

Instead, the optical transducer may be of the reflective type in which its positionable device includes a first reflector that preferentially re-

flects the first light, and a second reflector that preferentially reflects the second light, such reflectors acting in cooperation such that the relative amount of the first light and the second light reflected into the return optical fiber changes with the position of the actuator.

The actuator for moving the positionable device of the optical transducer is responsive to a command input, which may be controlled by any suitable parameter such as linear position, rotary position, temperature, pressure, flow, fluid level, electrical current or electrical voltage.

The apparatus also contains a photodetector operatively arranged at the output end of the return optical fiber for measuring the intensity of light at such output end, and generating a voltage responsive to such light intensity, thereby to measure the return fiber output light intensities corresponding to the first light and the second light. The photodetector apparatus may utilize either wavelength dispersion or wavelength filters to produce a first detector voltage proportional to the intensity of the first light, and also to produce a second detector voltage proportional to the intensity of the second light.

Another way of determining the light intensity is to alternately direct the first light and second light into the outgoing optical fiber, and the photodetector apparatus utilizes the time sequence to produce a first detector voltage proportional to the intensity of the first light and also to produce a second detector voltage proportional to the intensity of the second light.

The apparatus also contains an electronic signal processor responsive to detector voltages corresponding to the first light and second light. The electronic signal processor divides the first detector output voltage by the second detector output voltage to produce a first ratio, and also produces an output signal the magnitude of which is proportional to such first ratio for analog operation. This signal processor then tests this first ratio against a first constant and also against a second constant for digital operation, and if the ratio is greater than, or equal to, such first constant the signal output is activated, and if the ratio is less than, or equal to, such second constant then the signal output is deactivated.

The apparatus also contains an output controller having activated and deactivated states responsive to the controller signal output of the electronic signal processor. If the aforementioned first ratio, as tested by this signal processor, is less than the first constant and also greater than the second constant, then the actuator is considered to be in transition, whereupon the output controller is changed to the state opposite that which it had before the ac-

tuator entered the transition zone, producing a snap action of the change of state.

The apparatus also contains self-monitoring means having activated and deactivated states responsive to a status signal output of the electronic signal processor. The detector produces a third detector output voltage when neither of the first and second light generating means is operative. This third detector output voltage corresponds to the amount of stray light being returned through the detector fiber. The electronic signal processor divides the sum of the first and second detector output voltages by this third detector output voltage to produce a second ratio. Under normal operation of the apparatus, this second ratio will be much greater than 2. When one of the optical components of the apparatus is not functional this second ratio will be approximately 2, and such ratio is then utilized by the signal processor to output the status signal indicating a fault in one of such optical components.

Throughout the specification, the term "light" is used to denote electromagnetic radiation in the vicinity of the visible spectrum, but it should be understood that the term also includes electromagnetic radiation in the infrared and ultraviolet regions.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an abbreviated schematic of one embodiment of the optical transducer part of the inventive fiber optic sensor apparatus, and illustrating a transmissive type of optical transducer.

Fig. 2 is a graph illustrating the wavelengths of red and green light in relation to the intensity of each, employed in the practice of the present invention.

Fig. 3 is a schematic of one preferred embodiment of the present invention and illustrating fiber optic sensor apparatus, the optical transducer part being of the transmissive type.

Fig. 4 is a schematic of another preferred embodiment, and illustrating the optical transducer part as being of the reflective type.

Fig. 5 is an enlarged perspective view of a representative position sensing, optical fiber transducer of the reflective type.

Fig. 6 is a vertical sectional view thereof, taken on line 6-6 of Fig. 5.

Fig. 7 is a partial elevational, partial sectional view thereof, tak-

en on line 7-7 of Fig. 6.

Fig. 8 is a diagram comparing voltage waveforms produced at various times, under different representative conditions of operation of the inventive apparatus.

Fig. 9 is a flow chart of the functions performed by the electronic signal processor part of the inventive apparatus, which illustrates implementing ratiometric time-multiplexed fiber optic discrete position measurement algorithm, including software snap-action.

Fig. 10 is a first fragmentary schematic view of the inventive apparatus, illustrating its application as a reflective-type pressure sensor.

Fig. 11 is a second fragmentary schematic view of the inventive apparatus, illustrating its application as a reflective-type liquid level switch.

Fig. 12 is a third fragmentary schematic view of the inventive apparatus, illustrating its application as a reflective-type sensor for flow metering.

Fig. 13 is an elevational view of the dual color-coated disk shown in Fig. 12.

MODE(S) OF CARRYING OUT THE INVENTION

The first preferred embodiment of the inventive fiber optical apparatus, or mode of carrying out the invention, is illustrated in Figs. 1-3.

Referring to Figs. 1 and 3, a light-source optical fiber or outgoing optical fiber 20 has a light receiving input end 21 and a light emitting output end 22. A light detector optical fiber or return optical fiber 23 has a light receiving input end 24 and a light emitting output end 25. Suitable light generating means are provided for generating a first light having a spectral distribution centered at a first wavelength $\lambda 1$, and a second light having a spectral distribution centered at a second wavelength $\lambda 2$. This is shown as a dual color light source 26 arranged to emit light alternately of two wavelengths $\lambda 1$ and $\lambda 2$. Typically, these may be light emitting diodes (LED) or LASERS, one for emitting a first light such as green, and the other emitting a second light such as red, or any other combination of two colors.

As depicted in Fig. 2, which plots wavelength (λ) against relative light intensity, the curve 28 for the green color, when its LED is energized, has a spectral bandwidth centered about a wavelength $\lambda 1$ of 560 nanometers (nm), and the curve 29 for the red color, when its LED is energized, has a spectral

bandwidth centered about a wavelength $\lambda 2$ of 655 nm. Means are shown for directing the first and second light beams generated by source 26 into the input end 21 of fiber 20, such means being represented by the arrow line 30 in Fig. 3. Light emitted by the output end 25 of fiber 23 is received, as represented by arrow line 31 in Fig. 3, by suitable detecting means 32 arranged to detect the intensity of light at such output end.

Suitable optical transducer means, indicated generally at 33, is shown in Figs. 1 and 3 as operatively interposed between the output end 22 of fiber 20 and the input end 24 of fiber 23. Such transducer means includes a positionable device and actuator means for moving such device. This device is shown as including a first or upper filter 34 and a second or lower filter 35 arranged in line, with their opposing ends contacting each another. These filters as a unit are slidably arranged rectilinearly and reciprocally in a sensor body 36. This filter unit is constantly biased upwardly by a suitable spring means 38 shown arranged below such unit, with the lower end of the spring bearing against a suitable support surface 39 in body 36, and at its upper end bearing against the lower end of filter 35.

The aforementioned actuator means is shown as a plunger 40 projecting upwardly and outwardly from sensor body 36 through a suitable opening provided therein. The lower end of actuator plunger 40 is suitably connected to the upper end of the aforementioned filter unit, and its upper end is exposed and adapted to be engaged by a member (not shown) the position of which is to be sensed. Such unillustrated member is adapted to apply a downward force, represented by arrow line 41 in Fig. 3, against the upper end of actuator plunger 40 and push it further into sensor body 36, thereby moving the filter unit against the urging of the compressible spring 38.

Upper filter 34 is selected such that its spectral bandwidth is centered about 560 nm, and hence will selectively pass green light, absorbing other colors. Lower filter 35 is selected such that its spectral bandwidth is centered about 655 nm to selectively pass red light, absorbing other colors.

When actuating force 41 does not exist, spring 38 holds the lower red filter 35 between the opposing ends 22 and 24 of fibers 20 and 23, respectively. However, when actuating force 41 exists, as depicted in Fig. 3, upper green filter 34 is positioned between fiber ends 22 and 24 so that a beam of light, represented by arrow line 42, passes through this filter 34. Obviously, when lower red filter 35 is positioned between fiber ends 22 and 24, as not illustrated, the light beam 42 passes through this filter 35.

Suitable electronic signal processor means, indicated generally at 43, are shown in Fig. 3 as operatively associated via arrow line 44 with dual light source 26; also via arrow line 45 with detector 32; further via arrow line 46 with digital control output state means 48, including output on/off relay means 49 and indicator 50; and still further via arrow line 51 with self-monitoring means 52, including on/off relay means 53 and indicator 54.

Signal processor 43 comprises a single chip microcontroller, the functions of which are to be described later herein, capable of controlling the sequencing of the red and green light sources by a voltage Vout transmitted through conductor 44, and measuring the voltage Vin transmitted through conductor 45. Voltage Vin represents the resultant light amplitude for each wavelength in time sequence, and controlling the voltage outputs through conductors 46 and 51 to control the relays and indicators of the output state means 48 and the self-monitoring means 52. The control is accomplished by means of an internally stored program, which conforms to the algorithm prepared for time multiplexed, ratiometric light measurement.

The apparatus schematized in Fig. 3 thus includes a discrete fiber optic position sensor of the transmissive type. The output state of the means 48 relies on the physical movement of switch actuator 40, which is mechanically connected to the pair of optical filters unit 34,35 located in the path of bicolored light source fiber 20, and detector fiber 23, both of these fibers 20 and 23 being fixed. The displacement of actuator 40 causes either the green or red filter to be placed in the path of the light beam 30 emitted from source 26, which has the effect of filtering the light 31 returned to the signal processor. Thus, the relative intensity of the first light and the second light returning from sensor 33 to detector 32 is dependent on the physical or "discrete" position of actuator 40.

The second preferred embodiment of the inventive fiber optical apparatus, or mode of carrying out the invention, is illustrated in Figs. 4-7.

Referring to Fig. 4, the apparatus there shown is similar to that shown in Fig. 3, except for a slightly different construction of optical transducer 331 and the disposition of the adjacent end portions of the outgoing optical fiber 201 and return optical fiber 231. Otherwise, the balance of the apparatus is similar to that disclosed in Fig. 3, and hence the same reference numerals have been applied in Fig. 4 to corresponding parts.

The positionable device of the optical transducer 331 is of the reflective type. Thus, the upper portion of a member 58 is coated with a layer

59 of a suitable color material to be reflective for the first light and absorptive for the second light. The lower portion of member 58 is similarly coated with a layer 60 of a suitable color material to be absorptive for the first light and reflective for the second light. The opposing ends of layers 59 and 60 are contiguous to each another. Assuming the first light and second light are the colors green and red, respectively, as considered in the example of Fig. 3, layer 59 is a green coating and layer 60 is a red coating.

Member 58 with its color coatings 59 and 60 resembles the filter unit shown in Fig. 3, in that it is displaceable rectilinearly in opposite vertical directions by a lower spring 381 and an upper actuator plunger 401. When a downward force, represented by arrow line 411 in Fig. 4, is applied to the upper end of actuator plunger 401, and is sufficient to overcome yieldable spring 381, member 58 with its color coatings 59 and 60 can be displaced from its upper position (not illustrated) to its lower position as illustrated in Fig. 4.

The end portion of outgoing optical fiber 201 adjacent its output end 221, and the end portion of return optical fiber 231 adjacent its input end 241, are suitably fixed in close side-by-side relation so that both these ends of the fibers are facing toward member 58. An incident light beam, represented by the line 421, emitted from output end 221 of fiber 201, is arranged to be trained on a spot 61 on one of the coated surfaces on member 58. The input end 241 of fiber 231 is directed toward this spot 61 to receive a reflected or return light beam, represented by arrow line 422. As illustrated in Fig. 4, incident light beam 421 is shown as impinging on the green coating 59 carried on member 58, from which coating the return light beam 422 is reflected. It is evident that if the light impingement spot 61 is located on the red coating 60, due to member 58 being in its upper position (not illustrated), the return light beam 422 will be reflected from this red coating 60.

While optical transducer 331 of the reflective type may be of any suitable construction, a preferred construction of the same is illustrated in Figs. 5-7. As there shown, the transducer includes a block-like body member 62 having mounting holes 63 adjacent its corners, four such holes being shown. These holes 63 are adapted to receive suitable fasteners, such as screws or bolts (not shown), for mounting the body on some suitable support (not shown). Body 62 is shown as having an integral flat-surfaced boss 64 on its upper end, from which a vertically elongated cavity or recess 65 extends downwardly into the main portion of this body, terminating near its lower and closed end. Preferably this recess 65 is defined, in transverse section, by a cylindrical wall surface 66.

Slidably arranged in this recess is a plunger 68 including a cylindrical stem 69 having a concentric, reduced cylindrical section 70 adjacent its lower end. Plunger 68 also includes a radially enlarged head 71, having a domed or rounded upper surface 72 and a downwardly facing annular flat shoulder 73.

Operatively interposed between the opposing faces of body boss 64 and plunger shoulder 73, is a bellows type spring 74 having a compressible and expandable side wall 75 of generally cylindrical configuration, and inturned annular flat flanges 76 at opposite ends of this side wall. Side wall 75 is formed from flexible thin sheet metal, corrugated at vertically spaced intervals to provide alternate annular folds and furrows. Flanges 76 are suitably sealingly connected to the flat surfaces of body boss 64 and plunger shoulder 73. The folds of side wall 75 flex or bend when the spring 74 is subjected to an axial load, offering return force when the load is removed. Spring 74 is shown in Fig. 8 in its fully expanded condition. The spring will yield resistively to shorten its axial length when the aforementioned load is applied by plunger head 71 being depressed.

Applied to the cylindrical peripheral surface of the upper half of the plunger reduced section 70 is a circumferential ring 78 of suitable red colored material. Contiguous to and below this red ring 78 is a circumferential ring 79 of suitable green colored material, which is applied to the cylindrical peripheral surface of the lower half of the plunger reduced section 70. These color rings 78 and 79 may be provided by painting the colored material on the surface of this plunger section 70.

Body member 62 is also shown as having an integral externally threaded cylindrical projection 80 which extends horizontally outwardly from one side of this body. Projection 80 has a passage extending therethrough, including an inner cylindrical section 81 and an outer tapered section 82 which flares outwardly toward the outer end of the projection. Partially arranged in this projection passage is an elongated connector member 83 for holding optical fibers 201 and 231. This connector 83 includes an inner cylindrical portion 84, an adjacent tapered portion 85, an enlarged cylindrical intermediate portion 86, and a reduced cylindrical outer portion 88. A bore 89 extends longitudinally completely through connector 83. Body inner passage section 81 receives inner connector portion 84 which is shorter in axial length than section 81, so as to leave a gap 90 which opens to body recess 65. The surface of connector tapered portion 85 is complementary to the surface of body tapered passage section 82 and is adapted to be seated thereon. The annular step between connector por-

tions 86 and 88 provides a shoulder 91 against which the inturned flange end 92 of a tubular nut 93 can bear when this nut is tightened. This nut has a threaded connection with body projection 80, as indicated at 94.

Connector 83 is adapted to hold optical fibers 201 and 231 side-by-side, with their respective ends 221 and 241 substantially flush with the inner end face of this connector. Gap 90 allows the passage of light between these ends of the fibers and the reflective surface of the colored coatings 78,79.

Bellows spring 74 is shown in Figs. 5-7 in its fully extended condition whereby the lower green colored coating 79 is positioned opposite and in spaced relation from ends 221 and 241 of fibers 201 and 231, respectively. If some object (not shown), the position of which is to be sensed, bears downwardly against the domed surface 72 of plunger 68, spring 74 will be compressed, allowing the lower green ring 79 to be displaced from a position opposite fiber ends 221 and 241 and moving the upper red ring 78 into a position opposite these fiber ends. When such object backs away from plunger 68, spring 74 will expand and raise the plunger so that red ring 78 will move out of and green ring 79 will move into operative position opposite fiber ends 221 and 241.

Operation of the fiber optic sensor apparatus can be best explained and understood in connection with Figs. 8 and 9.

Referring to Fig. 8, voltage is plotted against time. Time is indicated at zero time t0, and three successive times t1, t2 and t3. The time period during which the red LED is energized is indicated by the time interval tred. The time period during which the green LED is energized is indicated by the time interval tgreen. The time period during which neither LED is energized is indicated by the time interval tdark. The condition of de-energized and energized for the LEDs is represented by 1 = energized and 0 = de-energized.

Reading from top to bottom, the six voltage wave forms shown in Fig. 8 are designated I, II, III, IV, V and VI. Wave I represents when the red LED is de-energized and energized. Wave II represents when the green LED is de-energized and energized.

Wave III represents detector voltage, at times t1, t2 and t3, when the optical transducer is positioned with the red element in the incident light path (42 or 421) emitted from the outgoing optical fiber (20 or 201). It will be seen that voltage Vt1 is greater than voltage Vt2, and voltage Vt3 is zero since neither LED is energized.

Wave IV represents the detector voltage, at times t1, t2 and t3,

when the optical transducer is positioned with the green element in the light path (42 or 421) emitted from the outgoing optical fiber (20 or 201). It will be seen that voltage Vt1 is less than voltage Vt2, and voltage Vt3 is zero since neither LED is energized.

Thus, at time t1, Vt1 represents the magnitude of the voltage corresponding to the light transmitted to and measured at the detector (26) during the period when the red LED is energized. At time t2, Vt2 represents the magnitude of the voltage corresponding to the light transmitted to and measured at the detector (26) during the period when the green LED is energized. At time t3, Vt3 represents the magnitude of the voltage corresponding to the light transmitted to and measured at the detector (26) during the period when both the red and green LEDs are de-energized.

Wave V represents the detector voltage, at times t1, t2 and t3, when the transducer sensor is in transition between red and green and some of both the red and green elements are positioned in the incident light path (42 or 421) emitted from the outgoing optical fiber (20 or 201). In this condition, voltage Vt1 is equal to voltage Vt2, and greater than voltage Vt3 which is zero.

Wave VI represents the detector voltage upon a failure in any one of the optical components comprising the light source 26, either optical fiber 20,201 or 23,231, connectors such as 83, optical transducer 33 or 331, and photodetector 32. The detector voltage varies over time, dependent on the amount of stray light that is incident to the detector, as in the case of a broken fiber that may be exposed to ambient light.

Referring to Fig. 9, the flow chart there shown depicts the functions performed by the signal processor 43 for controlling a species of discrete position instrumentality, and also for indicating the operative status or failure of the position sensing apparatus.

Upon system power-up, diagnostic checks are first performed to determine that the microcontroller is capable of executing its program. Program memory and input/output circuits are checked, and if functional, the switch failure bit is cleared, and the corresponding relay output 53 and status indicator 54 are turned on.

The light source circuit is then enabled, and the red LED 26 is energized. After a short delay, the detector voltage, which corresponds directly to the amount of red light being transmitted through the detector or return optical fiber 231, is measured and stored as variable Vt1. The red LED is then de-energized.

The green LED 26 is energized, and after a second delay, the detector voltage corresponding to the amount of green light being transmitted through the return optical fiber 231 is measured, and stored as Vt2. The green LED is now also de-energized.

After a third delay, the detector voltage corresponding to the amount of stray light being transmitted through the return optical fiber 231 is measured and stored as Vt3. Under normal operation, this light amount is very small in relation to Vt1 and Vt2, and is near zero volts.

At this time, Vt1 is divided by Vt2, and the result is stored as a variable RGRATIO, i.e., (RED/GREEN RATIO). This RGRATIO is now tested. If greater than or equal to a selected predetermined constant ONMIN, i.e., (minimum RED/GREEN RATIO allowed to consider the optical transducer "ON"), the sensor is considered ON, and the output relay 49 and on/off indicator 50 of the signal processor are energized. If the RGRATIO is less than or equal to constant OFFMAX, i.e., (maximum RED/GREEN RATIO allowed to consider the optical transducer "OFF"), the sensor is considered OFF, and the output relay 49 and on/off indicator 50 of the signal processor are de-energized.

If RGRATIO is greater than OFFMAX but less than ONMIN, a second ratio must be calculated and tested to determine if a switch failure exists, or if the switch is in a transitional state, midway between off and on. If midway between states, it is desirable to invert the then existing or present state immediately upon entering this transition zone. This then is considered as SNAP ACTION, and provides a distinct, repeatable switching point for each direction of actuator motion. If a failure exists due to a broken optical fiber, connector, actuator, light source, or other optical component, it is desirable to respond to this immediately by freezing or holding the present state output relay 49 and indicator 50, and de-energizing the status ok relay 53 and indicator 54.

The difference between the two conditions is decided as follows. LDRATIO, i.e., (LIGHT/DARK RATIO), is calculated to be (Vt1 + Vt2)/Vt3. Under normal operation, the sum of Vt1 and Vt2 will always be the same (a large number), with Vt3 near zero volts. Thus, the LDRATIO will be large, whether the switch is on, off or in transition, and will be a number greater than, say, 10. If a malfunction exists, such as a cut fiber, Vt1 = Vt2 = Vt3, since the detector then sees only the ambient light level. Thus, the LDRATIO can never be more than (1 + 1)/1 = 2.

A third selected predetermined constant LDMIN, i.e., (minimum

LIGHT/DARK RATIO allowed to consider the optical transducer functional), is assigned a value, say, 10. If the LDRATIO is equal to or greater than 10, and the snap action has not taken place in the previous measurement cycle, the present output relay state is inverted, or "snapped". The program then returns to begin a new measurement cycle. If the snap action has taken place on the previous cycle, the present output state is held.

If the LDRATIO is less than LDMIN, the switch is considered as having failed. The present output STATE relay 49 and indicator 50 are maintained in their present state, and the STATUS OK relay 53 and indicator 54 are de-energized. The program then returns to begin a new measurement cycle.

If the source of the failure is located and repaired, the failure condition will correct itself without requiring any operator action.

Representative applications of the present invention are illustrated in Figs. 10-13.

In Fig. 10, a reflective type optical transducer 331a, similar to the one shown at 331 in Fig. 4, is illustrated in fragmentary fashion utilized as a pressure sensor. Similar reference numerals, except as distinguished by the suffix a, are employed in Fig. 10 to designate corresponding parts.

The upper end of an actuator rod 401a is shown suitably connected to a flexible diaphragm 94 which is movable by the pressure of fluid confined above this diaphragm. Changes in pressure of this fluid move up or down the member 58a having a green coating 59a and a red coating 60a. As illustrated in Fig. 10, this green coating is in operative position opposite fibers 201a and 231a, suggesting a high pressure above the diaphragm which has depressed the coated member and compressed spring 38a. If the fluid pressure decreases sufficiently, the red coating 60a will be shifted upwardly, by the return spring, into operative position. In this manner, transducer 331a serves as a pressure sensitive switch.

In Fig. 11, a reflective type optical transducer 331b, similar to the one shown at 331 in Fig. 4, is illustrated in fragmentary fashion utilized as a liquid level switch. Similar reference numerals are employed in Fig. 11 as are used in Fig. 4, except for the addition of the suffix b, to designate corresponding parts.

The upper end of an actuator rod 401b is shown as suitably pivotally connected to a lever 95, intermediate its length. One end of this rod is pivotally mounted on a suitable support as indicated at 96, and the other end carries a float 98. This float determines the level of liquid 99 in a container or

tank 100. As the liquid level falls below a predetermined level, the green coating 59b will be positioned opposite the ends of fibers 201b and 231b to, say, open a valve (not shown) for filling tank 100 with more liquid. As the liquid level and float rises so as to position the red coating 60b opposite the ends of fibers 201b and 231b, the said valve will shut off.

In Fig. 12, a reflective type optical transducer 331c, similar to the one shown at 331 in Fig. 4, except that green and red color coatings 59c and 60c, respectively, are mounted on a rotatable support member 58c, instead of the rectilinearly movable members 58,58a and 58b shown in Figs. 4, 10 and 11. Similar reference numerals, except as distinguished by the suffix c, are employed in Figs. 12 and 13, to designate corresponding parts.

Rotatable member 58c enables the transducer 331c to be used as a flow meter. To this end, member 58c is shown as a rotatable disk, one half of the face of which is covered with the green coating 59c, and the other half with the red coating 60c, as illustrated in Fig. 13.

Disk 58c is shown as fast to a shaft 101 to which a paddle wheel 102 is also secured, this shaft being suitably journaled in a housing 103 having a fluid inlet 104 and a fluid outlet 105. Fluid flowing into this housing through its inlet, and discharged through its outlet, causes the paddle wheel to rotate. This will alternately bring the red and green colored coatings into operative position for impingement by the light beam emitted from outgoing optical fiber 201c, to be reflected back through return optical fiber 231c. By counting the color changes in a given period of time, by suitable means (not shown) but which may be incorporated in the signal processor, flow rate can be determined.

The electronic signal processor or sensor control module 43 can be arranged to handle several sensors, such as four sensors, and can be located remotely. Typical electrical outputs are +5 volts DC for transistor-transistor logic (TTL), and up to +40 volts DC for relay drives.

Two electrical signals and two indicators are provided for each sensor. One signal and indicator match the position of the sensor actuator (tripped or released). The other signal and indicator remain on only as long as the optical circuit is functional. If optical continuity is lost, the "sensor operational" indicator LED is de-energized and the status signal turns off.

The microcontroller based sensor control module 43 permits additional features to be included, such as recording the number of sensor transitions which may be helpful in establishing the useful life of what is being controlled, logging the time of each transition, and providing modem interface.

With multiple sensors, the microcontroller module permits Boolean logic output combining sensors.

The measurement technique can be extended to more than two positions or parameters by increasing the number of colored zones on the actuator. The signal processing techniques can be applied to multiple light sources and their corresponding colored zones to resolve the position of the actuator within each of the colored zones.

From the foregoing, it will be seen that the disclosed embodiments and applications of the inventive fiber optic sensor apparatus achieve the stated objects. Instead of the digital mode of operation of discrete position control, an analog mode of operation for position measurement may be obtained by overlapping dual colored wedge-shaped filters. Other modifications may occur to those skilled in the art. The scope of the invention is intended to be measured by the appended claims.

CLAIMS

1. Fiber optic sensor apparatus, comprising in combination:

(a) an outgoing optical fiber having input and output ends;

(b) a return optical fiber having input and output ends;

(c) first light generating means for generating a first light having a spectral distribution centered at a first wavelength;

(d) second light generating means for generating a second light having a spectral distribution centered at a second wavelength;

(e) means for directing beams of said first and second lights into said input end of said outgoing optical fiber;

(f) optical transducer means, including a positionable device, operatively interposed between the output end of said outgoing optical fiber and the input end of said return optical fiber, operative to modify the light intensity of said first and second lights, at said input end of said return optical fiber, in a dissimilar manner as a function of change of position of said device;

(g) detecting means for measuring the output light intensities at said output end of said return optical fiber; and

(h) electronic signal processor means responsive to the ratio of said output light intensities.

2. Apparatus according to claim 1, wherein said optical transducer means also includes an actuator means for moving said positionable device and responsive to a command input.

3. Apparatus according to claim 2, wherein the optical transducer is of the transmissive type.

4. Apparatus according to claim 3, wherein said positionable device includes a first optical filter that preferentially transmits said first light and a second optical filter that preferentially transmits said second light, said optical filters being arranged so that the relative amount of said first light and said second light transmitted into said input end of said return optical fiber changes

with the position of the actuator.

5. Apparatus according to claim 3 or 4, wherein said detecting means utilizes wavelength filtering to produce a first detector voltage proportional to the intensity of said first light and also to produce a second detector voltage proportional to the intensity of said second light.

6. Apparatus according to claim 2, wherein the optical transducer is of the reflective type.

7. Apparatus according to claim 6, wherein said positionable device includes a first reflector that preferentially reflects said first light and a second reflector that preferentially reflects said second light, said reflectors being arranged so that the relative amount of said first light and said second light reflected into said input end of said return optical fiber changes with the position of the actuator.

8. Apparatus according to claim 6 or 7, wherein said detecting means utilizes wavelength dispersion to produce a first detector voltage proportional to the intensity of said first light and also to produce a second detector voltage proportional to the intensity of said second light.

9. Apparatus according to claim 2, wherein said first light and said second light are alternatively directed into said input end of said outgoing optical fiber and said detecting means utilizes the time sequence to produce a first detector output voltage proportional to the intensity of said first light and also to produce a second detector output voltage proportional to the intensity of said second light.

10. Apparatus according to claim 4 or 7, wherein said signal processor means divides said first detector output voltage by said second detector output voltage to produce a first ratio, and also produces an output signal the magnitude of which is proportional to said first ratio.

11. Apparatus according to claim 10, wherein said signal processor means tests said first ratio against a first constant and also against a second constant, and if said first ratio is greater than, or equal to, said first constant

said signal output is activated, and if said first ratio is less than, or equal to, said second constant then said signal output is deactivated.

12. Apparatus according to claim 11 and further comprising output control means having activated and deactivated states responsive to said signal output, wherein said signal processor means tests said first ratio and if it is less than said first constant and also greater than said second constant then said actuator is considered to be in transition and said output control means is changed to the state opposite that which it had before the actuator entered the transition zone, thereby producing a snap action of the change of state.

13. Apparatus according to claim 10 and further comprising self-monitoring means having activated and deactivated states responsive to a status signal, wherein said detecting means produces a third detector output voltage when neither of said first and second light generating means is operative, said third detector output voltage corresponding to the amount of stray light being returned through said return optical fiber; said signal processor means dividing the sum of said first and second detector output voltages by said third detector output voltage to produce a second ratio which, under normal operation, will be much greater than 2, and will be approximately 2 when any one of the optical components of the apparatus is not functional and said second ratio is utilized by said signal processor means to output said status signal indicating a fault in one of such optical components.

14. Apparatus according to claim 2, wherein more than two light sources are used to determine the location of the positionable device within multiple zones over the range of travel of said positionable device.

AMENDED CLAIMS

[received by the International Bureau on 2 March 1988 (02.03.88) original claims 1-14 amended; new claims 15-27 added (6 pages)]

1. Fiber optic sensor apparatus, comprising:

first light generating means for generating a first light having a spectral distribution centered at a first wavelength;

second light generating means for generating a second light having a spectral distribution centered at a second wavelength;

first optical transmission means for transmitting said first and second lights from a first location to a second location;

transducer means operatively arranged to receive the lights transmitted by said first optical transmission means, said transducer means having a member positionable in the path of said lights in response to the magnitude of a parameter, said member being operative to modify the intensities of such received lights in a dissimilar manner;

second optical transmission means for transmitting such modified lights from said transducer means to a third location;

detecting means operatively arranged to receive the light transmitted by said second optical transmission means and to measure the intensities thereof; and

processing means operatively arranged to indicate the magnitude of said parameter and to monitor the transmissive integrity of said transmission and transducer means as a function of the light intensities measured by said detecting means.

2. Apparatus according to claim 1, wherein said transducer means is of the transmissive type.

3. Apparatus according to claim 2, wherein said member includes a first optical filter that preferentially transmits said first light and a second optical filter that preferentially transmits said second light, said optical filters being arranged so that the relative amounts of said first light and said second light transmitted to said second optical transmission means changes with the position of said member.

4. Apparatus according to claim 2 or 3, wherein said detecting means utilizes wavelength filtering to produce a first detector voltage propor-

tional to the measured intensity of said first light and also to produce a second detector voltage proportional to the measured intensity of said second light.

5. Apparatus according to claim 1, wherein said transducer means is of the reflective type.

6. Apparatus according to claim 5, wherein said member includes a first reflector that preferentially reflects said first light and a second reflector that preferentially reflects said second light, said reflectors being arranged so that the relative amounts of such reflected first and second lights change with the position of said member.

7. Apparatus according to claim 5 or 6, wherein said detecting means utilizes wavelength dispersion to produce a first detector voltage proportional to the measured intensity of said first light and also to produce a second detector voltage proportional to the measured intensity of said second light.

8. Apparatus according to claim 1, wherein said first light and said second light are alternatively directed to said first transmission means, and wherein said detecting means utilizes such time sequence to produce a first detector output voltage proportional to the measured intensity of said first light and also to produce a second detector output voltage proportional to the measured intensity of said second light.

9. Apparatus according to claim 7 or 8, wherein said processing means divides said first detector output voltage by said second detector output voltage to produce a first ratio, and also produces an output signal having a magnitude proportional to the magnitude of said first ratio.

10. Apparatus according to claim 9, wherein said processing means tests said first ratio against a first constant and also against a second constant, and if said first ratio is greater than, or equal to, said first constant said output signal is provided, and if said first ratio is less than, or equal to, said second constant then said output signal is not provided.

11. Apparatus according to claim 10 and further comprising output

control means having activated and deactivated states responsive to said output signal, wherein said processing means tests said first ratio and if it is less than said first constant and also greater than said second constant then said actuator is considered to be in transition and said output control means is changed to the state opposite that which it had before the actuator entered the transition zone, thereby producing a snap action of the change of state.

12. Apparatus according to claim 9 and further comprising self-monitoring means having activated and deactivated states responsive to a status signal, wherein said detecting means produces a third detector output voltage corresponding to the intensity of stray light received by said detecting means when neither of said first and second light generating means is operative, said processing means dividing the sum of said first and second detector output voltages by said third detector output voltage to produce a second ratio which, under normal operation, will be much greater than 2, and will be approximately 2 when any one of the optical components of the apparatus is not functional, and said second ratio is utilized by said processing means to output said status signal indicating a fault in one of such optical components.

13. Apparatus according to claim 1, wherein more than two light sources are used to determine the location of said member within multiple zones over the range of travel of said member.

14. Apparatus according to claim 1 wherein said first optical transmission means is an optical fiber.

15. Apparatus according to claim 1 wherein said second optical transmission means is an optical fiber.

16. Apparatus as set forth in claim 1 wherein said first optical transmission means is a first optical fiber, and wherein said second optical transmission means is a second optical fiber.

17. Fiber optic sensor apparatus, comprising:

a light source;

first optical transmission means for transmitting light from said

source to a remote location,

transducer means arranged to receive light transmitted by said first optical transmission means, said transducer means having a member operatively arranged to modify the intensities of two different bands of light centered at two different wavelengths in a dissimilar manner as a function of a parameter;

a second optical transmission means for transmitting such modified intensities from said transducer to another location;

detecting means operatively arranged to receive light from said second optical transmission means and to measure the intensities of said light bands; and

processing means operatively arranged to indicate the magnitude of said parameter and to monitor the transmissive integrity of said transmission and transducer means as a function of the light intensities measured by said detecting means.

18. Apparatus according to claim 17, wherein said optical transducer means is of the transmissive type, wherein said member includes a first optical filter that preferentially transmits light of one of said bands and a second optical filter that preferentially transmits light of the other of said bands, said optical filters being arranged so that the relative amounts of such light transmitted therethrough change with the position of the actuator, said processing means divides a first detector output voltage for the light of said one of said bands by a second detector output voltage for the light of said other of said bands to produce a first ratio, and also produces an output signal the magnitude of which is proportional to said first ratio, and further comprising self-monitoring means having activated and deactivated states responsive to a status signal, wherein said detecting means produces a third detector output voltage when no light is generated, said signal processor means dividing the sum of said first and second detector output voltages by said third detector output voltage to produce a second ratio which, under normal operation, will be much greater than 2, and will be approximately 2 when any of the optical components of the apparatus is not functional, and said second ratio is utilized by said signal processor means to output said status signal indicating a fault in one of such optical components.

19. Apparatus according to claim 17, wherein said optical transducer means is of the reflective type, wherein said member includes a first reflector that preferentially reflects light of one of said bands and a second reflector that preferentially reflects light of the other of said bands, said reflectors being arranged so that the light intensity of said one of said bands and the light intensity of said other of said bands changes with the position of said member, said processing means divides a first detector output voltage for the light of said one of said bands by a second detector output voltage for the light of said other of said bands to produce a first ratio, and also produces an output signal the magnitude of which is proportional to said first ratio, and further comprising self-monitoring means having activated and deactivated states responsive to a status signal, wherein said detecting means produces a third detector output voltage when no light is generated, said processing means dividing the sum of said first and second detector output voltages by said third detector output voltage to produce a second ratio which, under normal operation, will be much greater than 2, and will be approximately 2 when any of the optical components of the apparatus is not functional and said second ratio is utilized by said signal processor means to output said status signal indicating a fault in one of such optical components.

20. Apparatus according to claim 17 wherein said first optical transmission means is an optical fiber.

21. Apparatus according to claim 17 wherein said second optical transmission means is a second fiber.

22. Apparatus according to claim 17 wherein said first optical transmission means is a first optical fiber, and wherein said second optical transmission means is a second optical fiber.

23. An optical transducer, comprising:

a body provided with an internal chamber;

a member movably mounted on said body, said member having one portion arranged within said body and being movable in response to a parameter-to-be-sensed.

first means for transmitting light into said chamber;

modifying means mounted on said member one portion for modifying the intensities of two different bands of light at two different wavelengths in a dissimilar manner as a function of the position of said member; and

second means for transmitting such modified bands of light from said chamber.

24. An optical transducer as set forth in claim 23, wherein said modifying means is of the transmissive-type and has a first filter for transmitting the light of one of said bands, and has a second filter for transmitting the light of the other of said bands.

25. An optical transducer as set forth in claim 23, wherein said modifying means is of the reflective-type, and has a first reflector for reflecting the light of one of said bands, and has a second filter for reflecting the light of the other of said bands.

26. An optical transducer as set forth in claim 23 wherein said member is slidably mounted on said body.

27. An optical transducer as set forth in claim 23, and further comprising biasing means for urging said member to move toward a predetermined position relative to said body when said parameter-to-be-measured is zero.

Fig. 1.

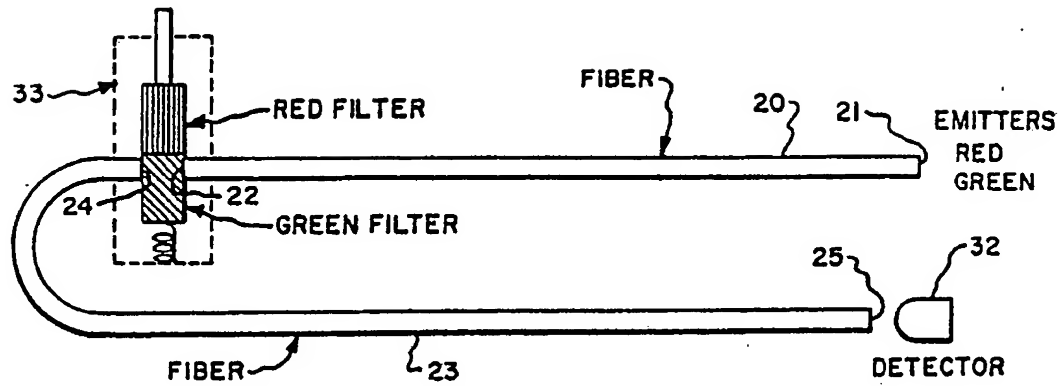

33
RED FILTER
FIBER
20
21
EMITTERS
RED
GREEN
24
22
GREEN FILTER
25
32
DETECTOR
FIBER
23

Fig. 2.

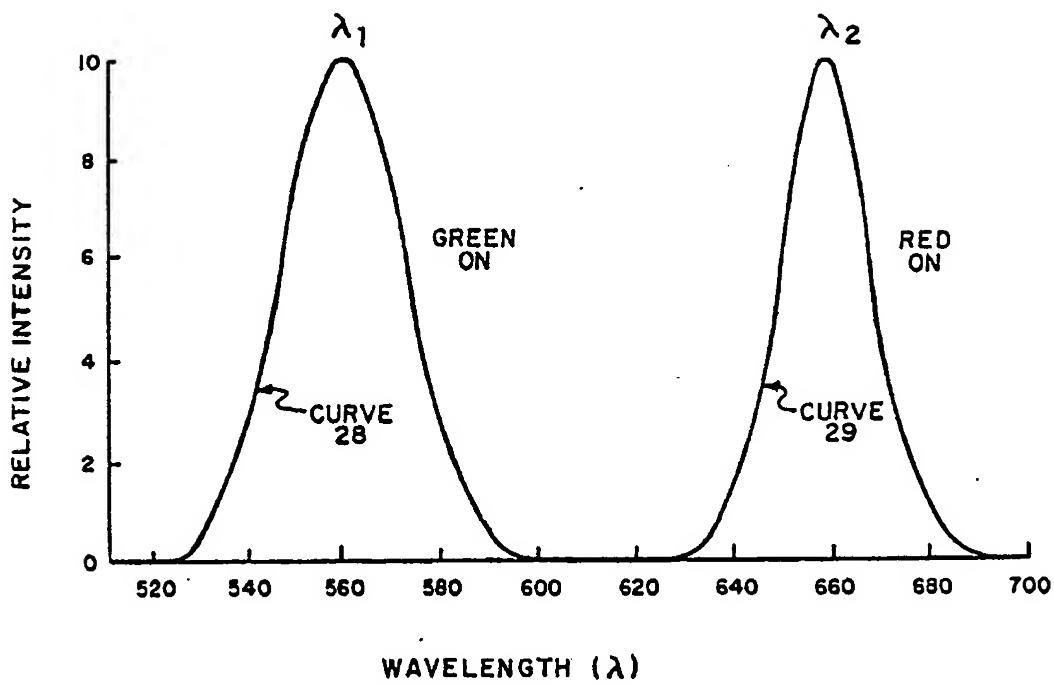

λ_1
λ_2
RELATIVE INTENSITY
10
8
6
4
2
0
GREEN ON
RED ON
CURVE 28
CURVE 29
520
540
560
580
600
620
640
660
680
700
WAVELENGTH (λ)

Fig. 3.

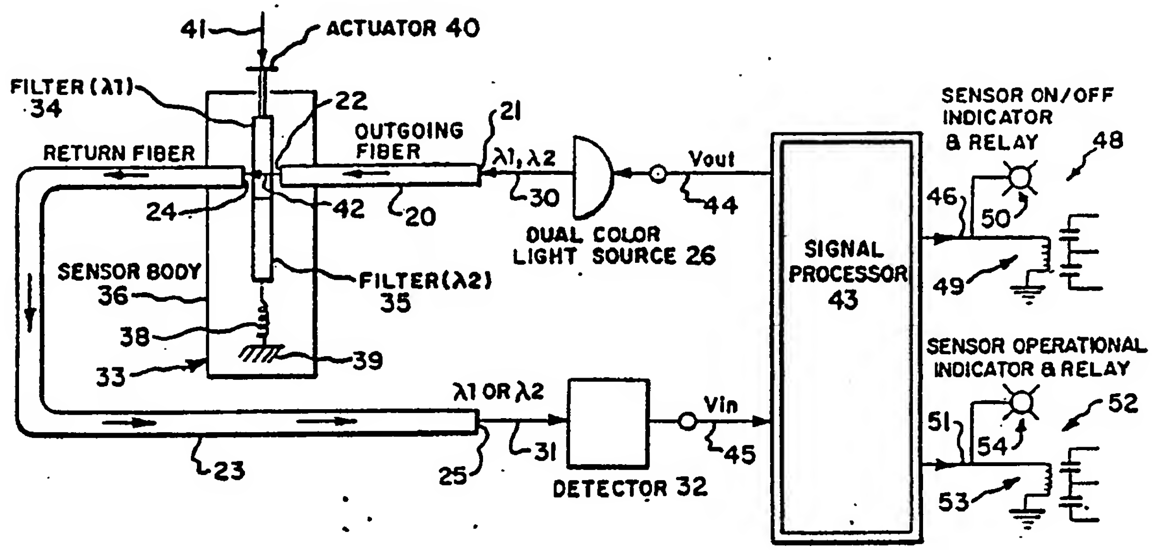
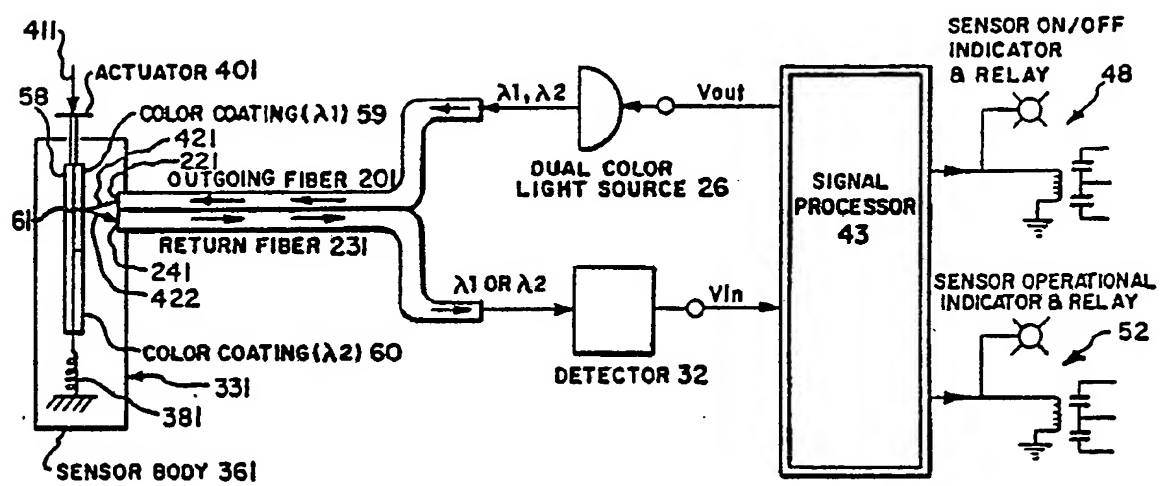

41
ACTUATOR 40
FILTER (λ1)
34
22
21
OUTGOING FIBER
RETURN FIBER
λ1, λ2
Vout
SENSOR ON/OFF INDICATOR & RELAY
48
30
44
24
42
20
DUAL COLOR LIGHT SOURCE 26
46
50
SENSOR BODY
36
FILTER(λ2)
35
SIGNAL PROCESSOR
43
49
38
33
39
SENSOR OPERATIONAL INDICATOR & RELAY
52
λ1 OR λ2
Vin
51
54
31
45
23
25
DETECTOR 32
53

Fig. 4.


411
ACTUATOR 401
58
COLOR COATING(λ1) 59
421
221
λ1, λ2
Vout
SENSOR ON/OFF INDICATOR & RELAY
48
OUTGOING FIBER 201
DUAL COLOR LIGHT SOURCE 26
61
RETURN FIBER 231
SIGNAL PROCESSOR
43
241
422
λ1 OR λ2
Vin
SENSOR OPERATIONAL INDICATOR & RELAY
52
COLOR COATING(λ2) 60
DETECTOR 32
331
381
SENSOR BODY 361

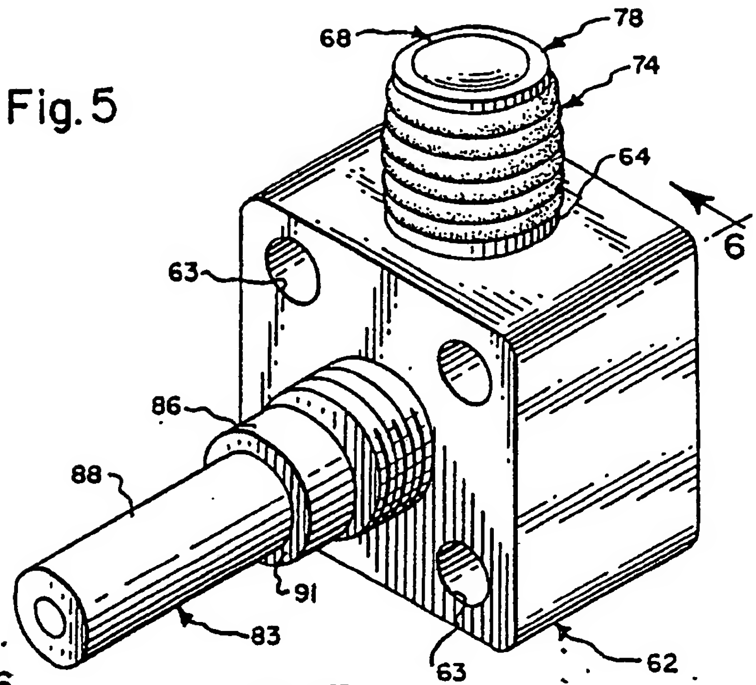
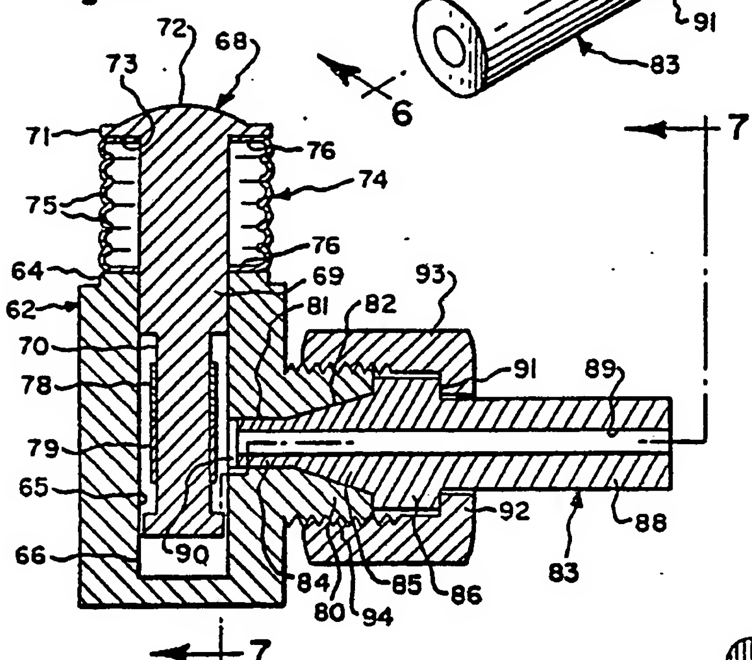


Fig. 5

Fig. 6.



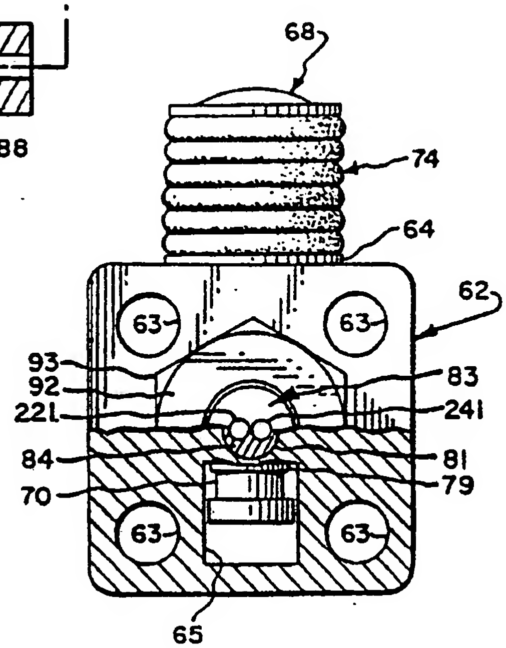


Fig. 7.

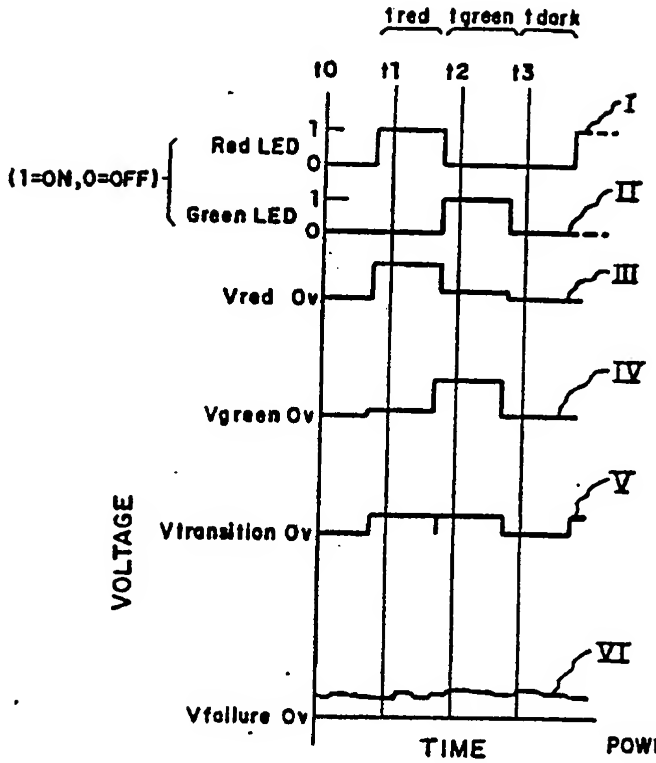

tred tgreen tdark
t0 t1 t2 t3
Red LED
(1=ON,0=OFF)
Green LED
I
II
III
IV
V
VI
Vred 0v
Vgreen 0v
Vtransition 0v
Vfailure 0v
VOLTAGE
TIME

Fig.8.

Fig. 9.

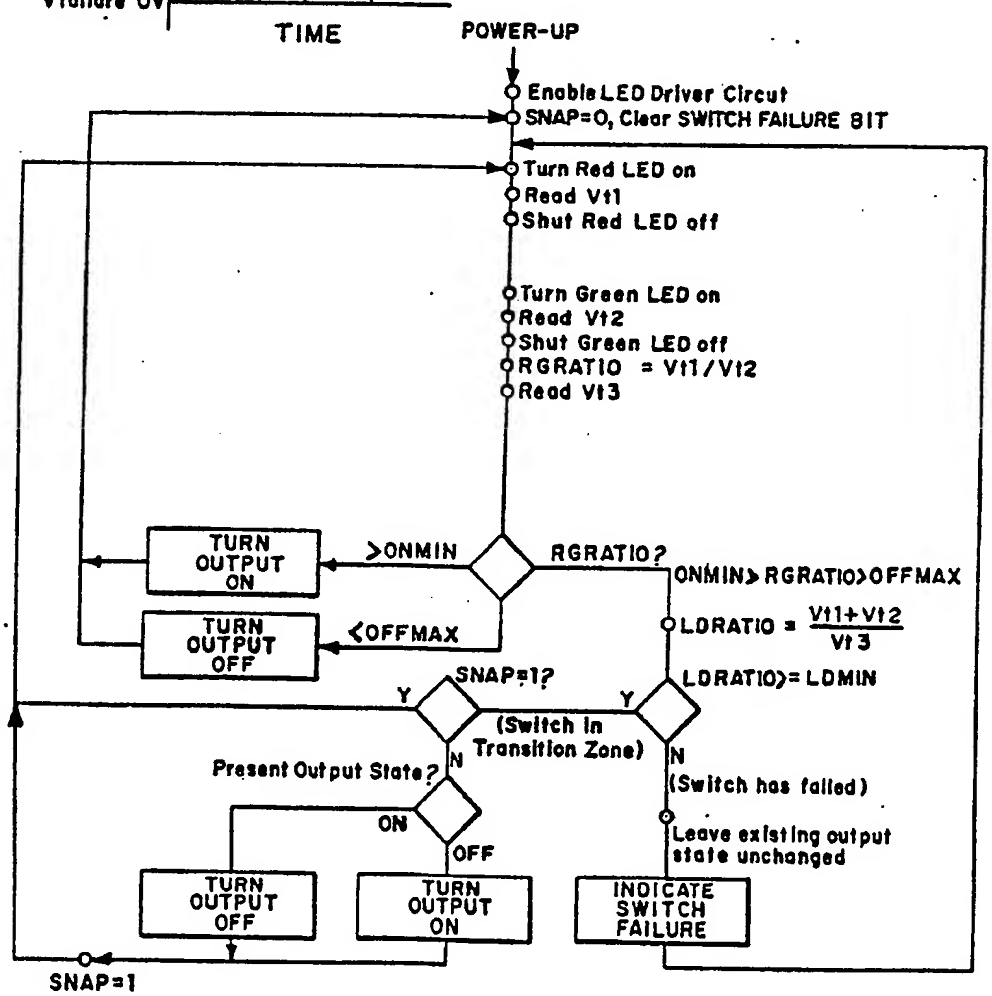

POWER-UP
Enable LED Driver Circuit
SNAP=0, Clear SWITCH FAILURE BIT
Turn Red LED on
Read Vt1
Shut Red LED off
Turn Green LED on
Read Vt2
Shut Green LED off
RGRATIO = Vt1/Vt2
Read Vt3
RGRATIO?
>ONMIN
TURN OUTPUT ON
<OFFMAX
TURN OUTPUT OFF
ONMIN>RGRATIO>OFFMAX
LDRATIO = (Vt1+Vt2)/Vt3
LDRATIO>=LDMIN
SNAP=1?
Y
Y
(Switch in Transition Zone)
N
N
(Switch has failed)
Present Output State?
ON
OFF
TURN OUTPUT OFF
TURN OUTPUT ON
Leave existing output state unchanged
INDICATE SWITCH FAILURE
SNAP=1

Fig. 10.

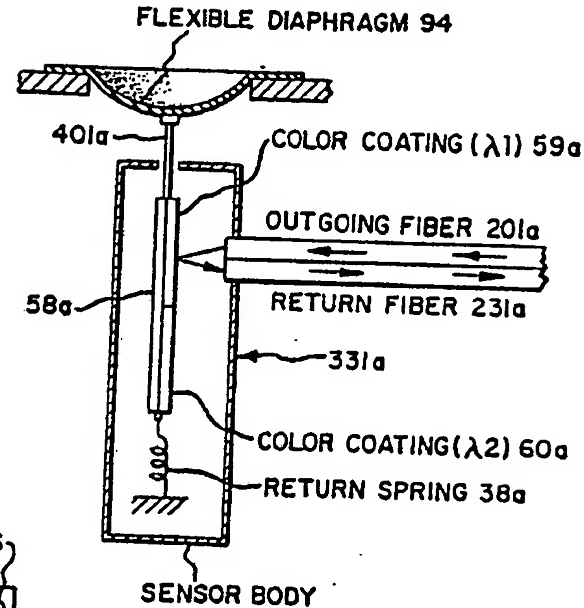


Fig. 11.

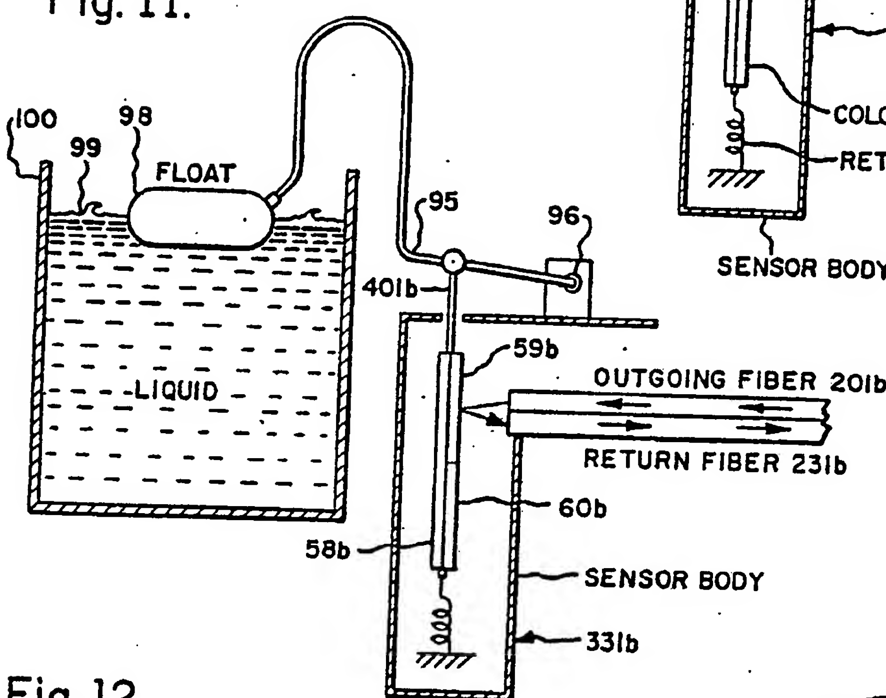


Fig. 13.

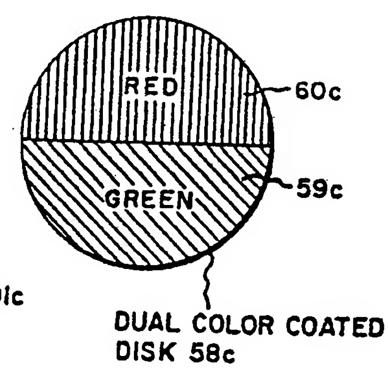
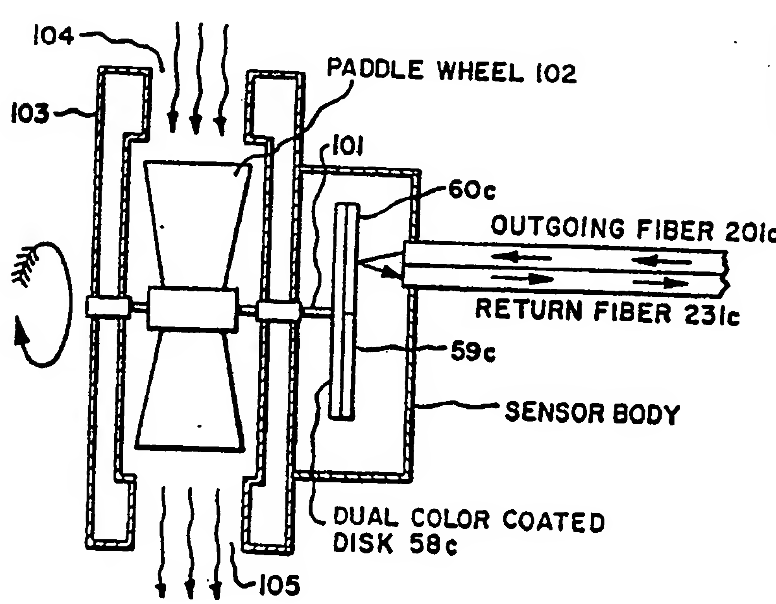


Fig. 12.



INTERNATIONAL SEARCH REPORT

International Application No PCT/US87/02404

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(4): H01J 5/16, G01D 5/34, G02B 6/02
US CL : 250/227, 231R: 350/96.29

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	350/96.29, 96.15, 96.13 250/227, 231R 73/655, 657, 800

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
T	US,A, 4,709,145 (SPILLMAN, JR.) 24 November 1987	1-14
T	US,A, 4,705,354 (ULRICH) 10 November 1987	1-14
A,P	US,A, 4,644,154 (BROGARDH ET AL.) 17 February 1987.	1-14
A	US,A, 4,572,948 (BROOKS) 25 February 1986	1-14
A	US,A, 4,562,348 (BROGARDH ET AL.) 31 December 1985	1-14
A	US,A, 4,560,868 (BROGARDH ET AL) 24 December 1985	1-14
A	US,A, 4,493,995 (ADOLFSSON ET AL) 15 January 1985	1-14
A	US,A, 4,356,397 (LENDERKING ET AL.) 26 October 1982	1-14
A	US,A, 4,356,396 (RUELL ET AL.) 26 October 1982	1-14

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
29 December 1987	25 JAN 1988
International Searching Authority [1]	**Signature of Authorized Officer**
ISA/US	Timothy P. Callahan

International Application No. PCT/US87/02404

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No [18]
A	US,A, 4,281,245 (BROGARDH ET AL.) 28 July 1981	1-14
A	US,A, 4,223,216 (QUICK ET AL.) 16 September 1980	1-14